

Prediction of endurance running performance for middle-aged and older runners

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The purpose of this study was to develop regression equations that would sufficiently predict the endurance running performance (ERP) of middle-aged and older runners ($n = 55$, 43–79 years). Among many independent variables which were selected as possible predictors of the ERP, oxygen uptake corresponding to the lactate threshold ($\dot{V}O_{2@LT}$), or age was found to be the single best predictor. Some variables representing training habits correlated significantly but only moderately with the ERP. Linear multiple regression equations developed in this study were:

$$\begin{aligned} V_{5km} &= 4.203 + 0.054X_1 - 0.028X_2 \quad (r = 0.87) \\ V_{5km} &= 4.436 + 0.045X_1 - 0.033X_2 + 0.005X_3 \quad (r = 0.89) \\ V_{10km} &= 4.252 + 0.042X_1 - 0.026X_2 \quad (r = 0.79) \\ V_{10km} &= 4.371 + 0.037X_1 - 0.031X_2 + 0.005X_3 \quad (r = 0.82) \\ V_M &= 3.207 + 0.048X_1 - 0.022X_2 \quad (r = 0.91) \\ V_M &= 3.707 + 0.038X_1 - 0.031X_2 + 0.005X_3 \quad (r = 0.93) \end{aligned}$$

where V_{5km} , V_{10km} and V_M are the mean running velocity at 5 km, 10 km and marathon races, respectively, and $X_1 = \dot{V}O_{2@LT}$ ($\text{ml kg}^{-1} \text{ min}^{-1}$), $X_2 = \text{age}$ (year), and $X_3 = \text{average running duration per workout}$ (min). We suggest that the ERP of middle-aged and older runners can be predicted from a linear combination of $\dot{V}O_{2@LT}$ and age or a combination of these variables plus average running duration per workout.

Keywords: middle-aged and older runners, prediction of endurance running performance, lactate threshold, training habits

An accumulated body of literature has demonstrated that success or failure in competitive distance running has been attributed primarily to the state of maximal oxygen uptake ($\dot{V}O_{2max}$), oxygen uptake corresponding to lactate threshold ($\dot{V}O_{2@LT}$), running economy at a standardized velocity, muscle fibre composition and others. The highest correlation ($r = -0.83$) of performance in 4.7 mile cross-country running detected by Costill¹ has been found with $\dot{V}O_{2max}$ from among many possible prerequisites. An even higher correlated relationship ($r = 0.91$) has been further described by Costill *et al.*² between $\dot{V}O_{2max}$ and 10-mile running performance in 16

well-trained runners, aged 25–48 years. However, Allen *et al.*³ have reported that, despite having 9% lower $\dot{V}O_{2max}$ values, master runners (mean(s.d.) age = 56(5) years) have the same performance in 10-km running as young runners (25(3) years) matched in terms of training distance, training pace and type of training.

Recent studies using a relatively homogeneous sample of highly trained runners in terms of both distance running performance and $\dot{V}O_{2max}$ have obtained low-to-moderate correlations ($r = -0.12$, -0.18 and -0.58) between $\dot{V}O_{2max}$ and race times^{4–6}. In other studies, $\dot{V}O_{2@LT}$ and/or running velocity corresponding to LT have been postulated as a better (possibly the single best) determinant of endurance running performance (ERP) than a number of prerequisites including $\dot{V}O_{2max}$ ^{7–13}.

The popularity of strenuous events such as the marathon and triathlon has increased tremendously over the last decade, such that the prerequisites for competing in these events should be investigated. It is logically assumed that a combination of several prerequisites such as $\dot{V}O_{2@LT}$, $\dot{V}O_{2max}$, age, muscle fibre type, body composition or training habits is critical to the optimal prediction of ERP. Slovic¹⁴ has indicated that there are systematic relationships between personal characteristics, training habits and performance in the marathon for young runners. However, little effort has been made to determine with a multivariate statistical procedure the relationship of these prerequisites to the ERP for middle-aged and older runners.

In as much as the runners consist of middle-aged and older individuals, it seems appropriate that age and training habits should also be included in a series of independent variables. The purpose of this study was to develop regression equations that would sufficiently predict ERP from age, $\dot{V}O_{2@LT}$ or $\dot{V}O_{2max}$, and training habit-related variables for middle-aged and older runners.

Materials and methods

Subjects

Fifty-one male, competitive runners, with a mean(s.d.) age of 57.3(8.9) years (43–79 years), served as subjects in this study. Statements of informed consent were obtained from each subject

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prior to the tests. The procedures used in this study were approved by the University of Tsukuba Health-Fitness Ethics Committee and were in accordance with the policy of American College of Sports Medicine for human experimentation. Mean(s.d.) values for the 51 runners were: stature 163.5(4.5) cm, weight 58.9(5.9) kg and estimated body fat 11.5(3.0)%. The percentage of body fat was derived from body density¹⁵, which was determined by the sum of the triceps and subscapular skinfolds¹⁶. Body mass index (BMI) which was calculated as (weight/stature²) $\times 10^4$ mean(s.d.) 22.0(1.8).

Training habits

The runners have been training mean(s.d.) 5.4(1.2) days week⁻¹ for competitive distance or marathon events for an average of 13.1(7.3) years before the tests. Current running distance per week and current duration of training per day averaged mean(s.d.) 54.5(21.2) km week⁻¹ and 60.7(21.2) min day⁻¹, respectively. Considering s.d.'s for these training characteristics, it is likely that both the training experience and the weekly running distance varied greatly among the runners, while there were relatively small individual differences in the training frequency.

Measurement of lactate threshold (LT) and $\dot{V}O_{2\max}$

The $\dot{V}O_{2@LT}$ and $\dot{V}O_{2\max}$ were measured during a continuous cycling exercise test on a Monark cycle ergometer. There is agreement among most researchers the $\dot{V}O_{2\max}$ elicited during normal cycle ergometer work is somewhat lower than that measured during uphill running on the treadmill when subjects are not well trained for cycling. Nevertheless, the $\dot{V}O_{2\max}$ was measured on a stationary cycle ergometer in the present study. The reason for adopting the cycle ergometer test was that electrocardiograms are much more accurately recorded during cycling exercise compared to treadmill running at relatively high speeds. Blood samples can also be more easily and more accurately obtained during cycling exercise as compared with treadmill running. The test started with 4 min unloaded cycling at 60 r.p.m. Following the warm-up, a work rate of 15 W was administered for the 5th min and thereafter increased by 15 W every minute until volitional exhaustion. All measurements of expiratory gases were determined by standard techniques of open-circuit spirometry, using a Mijnhardt Oxycon System OX-4 (The Netherlands). Gas analysers for O₂ and CO₂ involved in the processor system were calibrated immediately prior to and after each test with standard gases of known concentrations.

For detection of LT, a series of blood samples (1 ml each) were taken from the antecubital vein every minute during exercise. Blood lactate (La) determination was performed by the enzymatic electrode method¹⁷ with an Omron-Toyobo lactate analyser HER-100. LT was detected as the point in exercise of increasing intensity at which La abruptly increased in a non-linear (disproportionately high) fashion. For discerning the point at which the increase of La

concentration became non-linear, the log-log transformation method proposed by Beaver *et al.*¹⁸ was used.

The highest value of $\dot{V}O_2$ recorded during the test was considered as $\dot{V}O_{2\max}$. All the subjects reported here met at least two of the following three criteria for $\dot{V}O_{2\max}$ documentation: (1) the $\dot{V}O_2$ plateaued (<150 ml min⁻¹) despite increasing exercise intensity; (2) the highest respiratory exchange ratio was greater than 1.10; and (3) the highest heart rate was greater than 90% of the age-predicted maximal heart rate (220 - age). Forty-seven out of the 51 subjects met all the three criteria. Time taken to reach $\dot{V}O_{2\max}$ ranged from 15–23 min.

Statistics

A linear multiple regression analysis, with the stepwise procedure, was applied to the correlation matrix in order to extract a combination of several variables, which in turn provided the optimal prediction of each distance running performance. Dependent variables were mean running velocity at 5 km (V_{5km}), 10 km (V_{10km}), and marathon (V_M). Standard error of estimate (SEest) was computed as the square root of the unpredictable portion of the variance in a set of observations; that is, SEest = $\sqrt{\Sigma(Y - Y')^2/n}$, where Y is the actual score, Y' is the predicted score from the regression line, and n is the number of subjects. Significant correlations were only accepted when P values were less than 0.05.

Results

A summary of the selected physiological, anthropometric and running performance characteristics of the subjects is given in Table 1. Results of the Pearson

Table 1. Descriptive statistics for selected variables

	Mean(s.d.)
Age (year)	57.3(8.9)
Stature (cm)	163.5(4.5)
Weight (kg)	58.9(5.9)
BMI	22.0(1.8)
Body fat (%)	11.5(3.0)
HR (beats min ⁻¹)	62.8(9.0)
SBP (mmHg)	139.0(14.0)
DBP (mmHg)	80.9(9.8)
$\dot{V}O_{2@LT}$ (ml kg ⁻¹ min ⁻¹)	27.7(6.3)
$\dot{V}O_{2\max}$ (ml kg ⁻¹ min ⁻¹)	47.1(8.3)
<i>Training characteristics</i>	
experience (year)	13.1(7.3)
distance (km week ⁻¹)	54.5(21.1)
duration (min day ⁻¹)	60.7(20.7)
frequency (day week ⁻¹)	5.4(1.2)
intensity (m sec ⁻¹)	2.88(0.66)
V_{5km} (m sec ⁻¹)	4.09(0.57)
V_{10km} (m sec ⁻¹)	3.91(0.58)
V_M (m sec ⁻¹)	3.42(0.53)

BMI, body mass index; HR, pre-training heart rate; SBP, pre-training systolic blood pressure; DBP, pre-training diastolic blood pressure; $\dot{V}O_{2@LT}$, oxygen uptake ($\dot{V}O_2$) corresponding to lactate threshold (LT); $\dot{V}O_{2\max}$, maximal oxygen uptake; V_{5km} , mean running velocity during the best 5-km race; V_{10km} , mean running velocity during the best 10-km race; V_M , mean running velocity during the best marathon race

Table 2. Independent variables that were significantly correlated with the mean running velocity

$V_{5\text{km}}$	$\dot{V}_{\text{O}_2\text{@LT}}$ (0.83), Age (-0.79), $\dot{V}_{\text{O}_{2\text{max}}}$ (0.76), distance (0.45)
$V_{10\text{km}}$	$\dot{V}_{\text{O}_2\text{@LT}}$ (0.74), Age (-0.73), $\dot{V}_{\text{O}_{2\text{max}}}$ (0.72), distance (0.29)
V_M	$\dot{V}_{\text{O}_2\text{@LT}}$ (0.88), Age (-0.86), $\dot{V}_{\text{O}_{2\text{max}}}$ (0.83)

Values in parentheses denote correlation coefficients; definitions as in Table 1

Table 3. Linear multiple regression equations

$V_{5\text{km}}$	$= 4.203 + 0.054X_1 - 0.028X_2, r = 0.87, \text{SEest} = 0.306$
$V_{5\text{km}}$	$= 4.895 - 0.036X_2 + 0.027X_3, r = 0.83, \text{SEest} = 0.322$
$V_{5\text{km}}$	$= 4.436 + 0.045X_1 - 0.033X_2 + 0.005X_4, r = 0.89, \text{SEest} = 0.265$
$V_{10\text{km}}$	$= 4.252 + 0.042X_1 - 0.026X_2, r = 0.79, \text{SEest} = 0.348$
$V_{10\text{km}}$	$= 4.123 - 0.027X_2 + 0.028X_3, r = 0.77, \text{SEest} = 0.370$
$V_{10\text{km}}$	$= 4.371 + 0.037X_1 - 0.031X_2 + 0.005X_4, r = 0.82, \text{SEest} = 0.335$
$V_{10\text{km}}$	$= 4.077 - 0.031X_2 + 0.026X_3 + 0.062X_4, r = 0.80, \text{SEest} = 0.349$
V_M	$= 3.207 + 0.048X_1 - 0.022X_2, r = 0.91, \text{SEest} = 0.220$
V_M	$= 3.707 + 0.038X_1 - 0.031X_2 + 0.005X_4, r = 0.93, \text{SEest} = 0.199$
V_M	$= 5.858 - 0.052X_2 + 0.067X_4, r = 0.90, \text{SEest} = 0.265$

Where $V_{5\text{km}}$, $V_{10\text{km}}$ and V_M are the mean running velocity (m sec^{-1}) at 5 km, 10 km and marathon, respectively and $X_1 = \dot{V}_{\text{O}_2\text{@LT}}$ ($\text{ml kg}^{-1} \text{min}^{-1}$), $X_2 = \text{age}$ (year), $X_3 = \dot{V}_{\text{O}_{2\text{max}}}$ ($\text{ml kg}^{-1} \text{min}^{-1}$), and $X_4 = \text{average running duration per workout}$ (min)

product-moment correlation analysis showed that $\dot{V}_{\text{O}_2\text{@LT}}$, $\dot{V}_{\text{O}_{2\text{max}}}$ and age were the three independent variables that were correlated most strongly with $V_{5\text{km}}$, $V_{10\text{km}}$ and V_M (Table 2). Associations of other independent variables such as BMI or training characteristics with the running performances were statistically insignificant or only low to moderate.

Table 3 summarizes the linear multiple regression equations, with partial regression coefficients, developed in this study. Variables selected for prediction of the $V_{5\text{km}}$, $V_{10\text{km}}$ or V_M were any two or three prerequisites from $\dot{V}_{\text{O}_2\text{@LT}}$, $\dot{V}_{\text{O}_{2\text{max}}}$, age and average running duration per workout. The SEest for each prediction equation is also included in Table 3, which is the statistic commonly used to quantify the accuracy of a prediction equation.

Discussion

Although it has previously been suggested that $\dot{V}_{\text{O}_{2\text{max}}}$ is the single best indicator of ERP, more recently, several studies^{8, 11, 19, 20} have found that $\dot{V}_{\text{O}_2\text{@LT}}$ is a better predictor of ERP than $\dot{V}_{\text{O}_{2\text{max}}}$. Interestingly, Tanaka *et al.*²⁰ reported that even in the improved state in terms of ERP and $\dot{V}_{\text{O}_2\text{@LT}}$, higher relationships ($r \geq 0.75$) between the ERP and LT-related variables held up consistently over the 9-month training period. It is of more interest to note that ERP changes were more strongly accounted for by the $\dot{V}_{\text{O}_2\text{@LT}}$ changes, rather than changes in other physiological attributes including $\dot{V}_{\text{O}_{2\text{max}}}$ ²⁰. In the present study, high relationships were also found between the $\dot{V}_{\text{O}_2\text{@LT}}$ and ERP ($r = 0.74 \sim 0.88$) and

between $\dot{V}_{\text{O}_{2\text{max}}}$ and ERP ($r = 0.72 \sim 0.83$) at all distances. Therefore, a high $\dot{V}_{\text{O}_2\text{@LT}}$ and/or $\dot{V}_{\text{O}_{2\text{max}}}$ as well as age could be considered, even among older runners, as one of the most influential determinants of performance in distance running and marathon events. The fact that age was found the second most influential variable in predicting ERP may be simply because running ability in general decreases linearly with ageing.

We reported that the ERP of middle-aged and older runners could be predicted with a relatively high accuracy by a single predictor of $\dot{V}_{\text{O}_2\text{@LT}}$ or $\dot{V}_{\text{O}_{2\text{max}}}$, or by a combination of either of these predictors with more easily measurable indices such as age, atherogenic index, Katsura index or systolic blood pressure²¹. However, the relationships of the training habits with ERP have not been investigated in middle-aged and older runners. It is necessary to examine the relative contribution of training habit factors as a single entity or in combination, to the ERP. Contrary to our expectations, all variables on the training habits of the subjects, with the exception of weekly running distance, did not show significant correlations with ERP.

In previous investigations^{4, 22–24}, success in ERP has been found to be related to the training indices which include total workouts and workout days, average running velocity in m min^{-1} , maximum running distance per week, average distance per workout, average distance per week and total duration and distance of training run. Above all, average distance per workout, average distance per week and total distance run during the 9 weeks preceeding the race were the most powerful factors related to improved race performance²². World-class distance runners usually run twice a day and between 110 and 240 km week⁻¹ for 45–52 weeks year^{-1, 6}. Less well-accomplished runners train below these levels and it has been recommended that aspiring marathoners train for at least 3 months at progressively greater weekly distances up to an average of 80 km week⁻¹ to ensure completion of a marathon race²³. Slovic²⁴ has predicted that 35–50% of the variation in ERP is attributed to the maximum miles run in 1 week and 34–49% of the variation in ERP to the total miles run in the 8 weeks prior to the race. In the present cross-sectional data, correlations of training characteristics with ERP were statistically insignificant or only low to moderate (average distance per week; $r = 0.29 \sim 0.45$). Therefore, it is difficult to estimate ERP with any high accuracy from training habits in the middle-aged and older runners as compared with younger subjects. In future, however, it is important to analyse in more detail the relationship among ERP and training habits in longitudinal data for middle-aged and older runners.

When $\dot{V}_{\text{O}_2\text{@LT}}$, age and one more factor (for example, average running duration per day, weight or BMI) were entered into stepwise multiple regression analysis, they accounted for 79% and 67% of the variance in $V_{5\text{km}}$ and $V_{10\text{km}}$ respectively, which were not significantly different from 76% and 63% accounted for by a combination of $\dot{V}_{\text{O}_2\text{@LT}}$ and age. It is, therefore, suggested that the addition of another variable does not raise predictive accuracy to a

statistically meaningful level. The SEest of the predicted ERP seems to be small, particularly in view of the heterogeneous nature of the sample studied.

In conclusion, we suggest that ERP of middle-aged and older runners with heterogeneous training habits can be predicted with high accuracy by $\dot{V}O_2$ @LT and age or possibly a combination of these variables plus average running duration per workout. The prediction equations developed in this study could be expanded for use in a greater population of middle-aged and older runners, from the moderately to the highly trained.

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